

NASA Grant NAG 5-787
Final Report

FINAL REPORT

NASA GRANT NAGS-7587
(Oklahoma State University AA-5-51109)

TERRSTRIAL ENVIRONMENTAL VARIABLES DERIVED FROM EOS PLATFORM SENSORS

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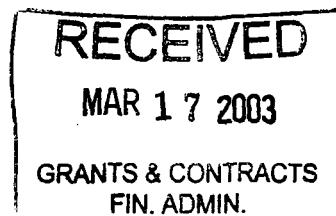
Co-Investigators

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Period of Performance
August 1998 – December 2001



Introduction

This final report considers a portion of related grants at Oklahoma State University (OSU), the University of Maryland College Park and the University of Toledo. This report covers the Oklahoma State University portion of the work.

Project Goals

The three main objectives of the overall project were:

1. Adaptation of environmental constraint methods to take advantage of EOS sensors, specifically, MODIS, ASTER, and Landsat-7, in addition to the PM AVHRR observations
2. Refinement of environmental constraint methods based on fundamental scientific knowledge.
3. Assessment of spatial scaling patterns in environmental constraint measurements to evaluate the potential biases and errors that occur when estimating regional and global-scale NPP patterns with moderate to coarse satellite observations.

These goals were modified because, on one hand, MODIS data did not become available until after the first year of the project and because of project staffing issues at the University of Maryland. The OSU portion of the project contained a modest amount of funding and responsibility compared to the University of Maryland and the University of Toledo.

Project Staffing

In his final report to NASA, Investigator Goward has commented on the vexing personnel issues at the University of Maryland in his portion of the grant. Investigator Stadler agrees with Goward's conclusions and notes that this did make the cooperation more difficult. It should be emphasized that the situation did not cause friction between the universities.

The Oklahoma State University portion of the work was straightforward and was not internally hampered by personnel issues.

The following personnel worked on the OSU portion of the project:

Dr. Steve Stadler, Professor of Geography, OSU, Principal Investigator

Ms. Margaret Langley, M.S. student in Geography, OSU

Ms. Lori Schmitz, NSF-funded Research Experience for Undergraduates project*

Ms. Vicky Bernecky, NSF-funded Research Experience for Undergraduates project*

Mr. Bruce Battles, Lab Manager, Center for Applications of Remote Sensing, OSU*

*No charge to NASA

Oklahoma State University Work

In that PI Stadler had knowledge about Oklahoma landscapes and datasets of value to satellite assessments, the focus of the OSU portion of was to provide high-quality Oklahoma atmospheric and soil datasets suitable for validation of satellite algorithms. The study area was the state of Oklahoma in order to take advantage of the spatial coverage Oklahoma Mesonet and related instrumentation. In particular, we first built a period-of-Mesonet record climate assessment for 9 of the Mesonet sites representing the east/west climatic diversity in the state. We completed skeleton climatologies for the 9 sites. For any satellite scene of interest, we were able to assess the difference in the antecedent weather conditions to the averages for that time of year. This is of considerable importance to validations of satellite algorithms. Are we looking at "normal", "wet", or "dry" landscapes relative to the time of year? In that the hydrologic spatial variability across Oklahoma's vegetation ecotone can be pronounced (that is, an entire satellite scene is

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unlikely to be "wet" or "dry"), it is crucial to have a knowledge of this during validation of algorithms. Figure 1 shows the location of the sites across the state. Figure 2 shows the variables that were included in the climatologies for each site. The Oklahoma Mesonet project produces data sets that are quality-controlled (see <http://okmesonet.ocs.ou.edu/>). Daily files for each station were pulled from the Web-based archive. The data were in 5 min increments. Descriptive statistics were developed for the data set so as to have a final quality check of the data.

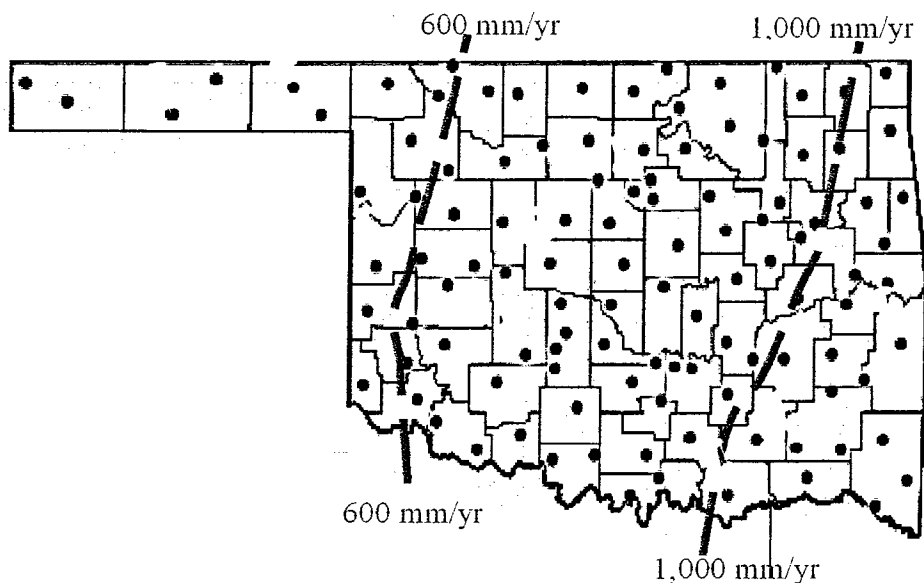


FIGURE 1

FIGURE 2	
Air temperature at 1.5 m	
Wind speed at 10 m	
Wind direction at 10 m	
Standard deviation of wind speed at 10 m	
Maximum wind gust	
Accumulated precipitation	
Station pressure	
Average solar radiation flux	
Air temperature at 9 m	
Wind speed at 2 m	
Soil temperature under sod at 10 cm	
Soil temperature under bare ground at 10 cm	
Soil temperature under sod at 5 cm	
Soil temperature under bare ground at 5 cm	
Soil temperature under sod at 30 cm	

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During the first year of the project, automated soil moisture at several depths became available at all Mesonet sites (see <http://okmesonet.ocs.ou.edu/oasis/>). At the beginning of Year 2, the OSU work focused on obtaining soil moisture data for the summer of 1997 for our 9 selected Mesonet sites of Figure 1. As the Mesonet did not have a fully developed automated soil moisture database, these data were more complicated to deal with than the core atmospheric and soil variables in more common use. Changeover in relevant Mesonet personnel slowed progress we were able to obtain the data, examine them to assure their basic quality, and ship them to Toledo and Maryland. The data consisted of soil moisture at 4 depths (operationalized as soil water potential) for half hour time increments from April through October 1997. This request resulted in changes to procedures at the Oklahoma Mesonet so that such soil moisture data requests are no longer a large problem. To accompany the soil moisture data, we pulled the daily time series of atmospheric parameters and soil temperatures for the same 9 site and times. Later, we obtained soil moisture and weather data for April through October 1999 and are placed them into usable form for further analysis at Maryland and Toledo.

A GIS database was developed for each of the 9 Mesonet sites of Figure 1. We delineated areas of 12 km radius around each site. Within those areas gathered the following digital data sets: USGS orthophotos (1 m resolution), NRCS land use/landcover (200 m resolution from color infrared photography), NRCS soils data (200 m), road networks, and sensor locations. These areas around the selected Mesonet sites were scanned via windshield survey to confirm the accuracy of our digital landcover database.

We used daily time steps from April through October of 1997 to analyze soil moisture at the 9 sites shown in Figure 1. We incorporated site coordinates, county roads, land use, soils, weather and aerial photo data into an ArcView project. We then divided the area around each site into 16 sectors representing 16 possible wind directions. Based upon the prevailing wind direction, we calculated a surface landscape coefficient using the percentage of land use types in dominant sector for each day. We then entered the landscape coefficients, air temperature, precipitation, solar radiation, wind speed, and soil texture as independent variables in stepwise multiple regression equations, formulating equations at two depths for each site. Results showed that the upwind landcovers did affect the other variables but the results varied between the 9 sites.

The most intensive Oklahoma field work has been conducted at the Marena site some 20 km WSW of Stillwater. This Mesonet site (on rangeland surrounded by considerable forest cover to the east and south) was chosen for intensive study in a fashion parallel to the work at Toledo's Stranaham Arboretum. We implanted 9 Onset HOBOTM dataloggers wired thermistors around the Mesonet enclosure over an area of approximately .25 sq km (See Figure 3). The thermistors were tied to various vegetation types in order to gain an appreciation of local variations in "skin temperature" for comparison with satellite sensors. The thermistors recorded temperatures at 2 min intervals and the data were downloaded, checked, and sent to Toledo on a bi-weekly basis. Heavy June rains (> 150 mm) and the digging of small animals caused problems with sensors but we managed to keep most sensors running most of the time during the summer which turned out to be the hottest in the last quarter century. In this study we assessed the ability of MODIS surface temperature estimations to match up with *in situ* data. The Marena Mesonet site is broadly rolling with a mix of tallgrass prairie and crosstimbres forest. Adjacent to the Mesonet site were 9 thermistors spaced approximately 50m apart, attached to various species of grasses and small bushes, and providing 2-minute temperature data. Thus, we had a several air and surface temperature measurements within a single MODIS pixel. MODIS scenes were processed using a modified split window method (Czajkowski et al 1998) to estimate surface temperature. We attempted to minimize the impacts of the presence of clouds and low level water vapor using daily time series of Mesonet solar radiation data. Interestingly, this left us with only 6 suitable MODIS scenes from the warm season of 2000. We compared satellite-derived temperatures with

HOBO Sites

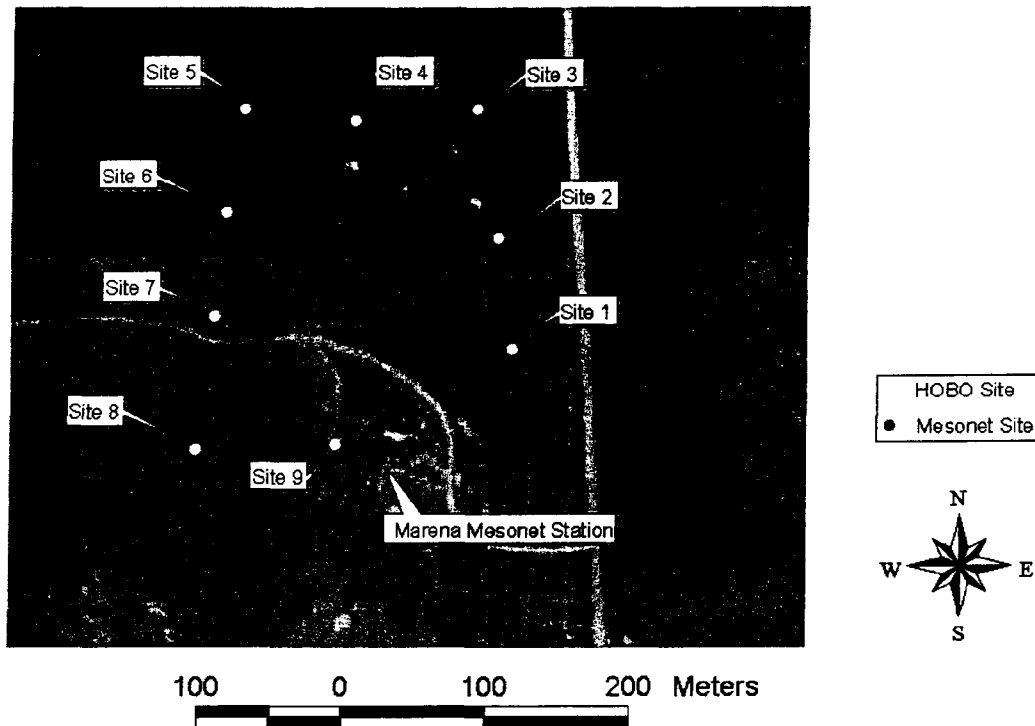


FIGURE 3

the *in-situ* air and surface temperatures and found a reasonable correspondence of variability between skin temperatures derived from MODIS and those from the HOBO thermistors. In almost all cases the HOBO thermistors gave considerably higher skin temperatures (> 5 K difference). However, within-MODIS-pixel variations of the thermistors suggested some differences between satellite and *in situ* data can be explained by vegetative heterogeneity over this "homogenous" grassland landscape.

Our final effort involved direct comparison of skin temperatures as sensed by MODIS as compared with skin temperatures as sensed by 90 infrared thermometers mounted at 2 m at Mesonet sites. We used 6 MODIS overpasses from the summer of 2000 and compared MODIS land surface temperatures with those of infrared thermometers under clear sky conditions. The results are given in Figure 4. The figure is a bivariate plot of temperatures for all six overpasses. In this figure it is obvious that there are calibration problems in a few of the infrared thermometers. It is also obvious that there is a strong relationship between the MODIS and infrared thermometer skin temperatures. Yet, there is a bias of 2.55 K. This was perplexing but intriguing. The Mesonet infrared thermometers represent the largest exposure of such devices in the world. Why does the bias exist? We have theorized it is due to differences in regional land use and had some resolution of this effect in work outside the period of performance (See the "Follow-On Work" section).

Interaction with NSF Summer REU Program

During the second two summers (2000 and 2001) of the period of performance, Dr. Tom Wike at the Geography Department of Oklahoma State University hosted students in an 8-week NSF Research Experience for Undergraduates (REU). In each of these two summers, PI Stadler mentored an REU student and was able to supplement the NASA EOS project with GIS and image analysis work by undergraduates; their work evolved into co-authored presentations at professional meetings.

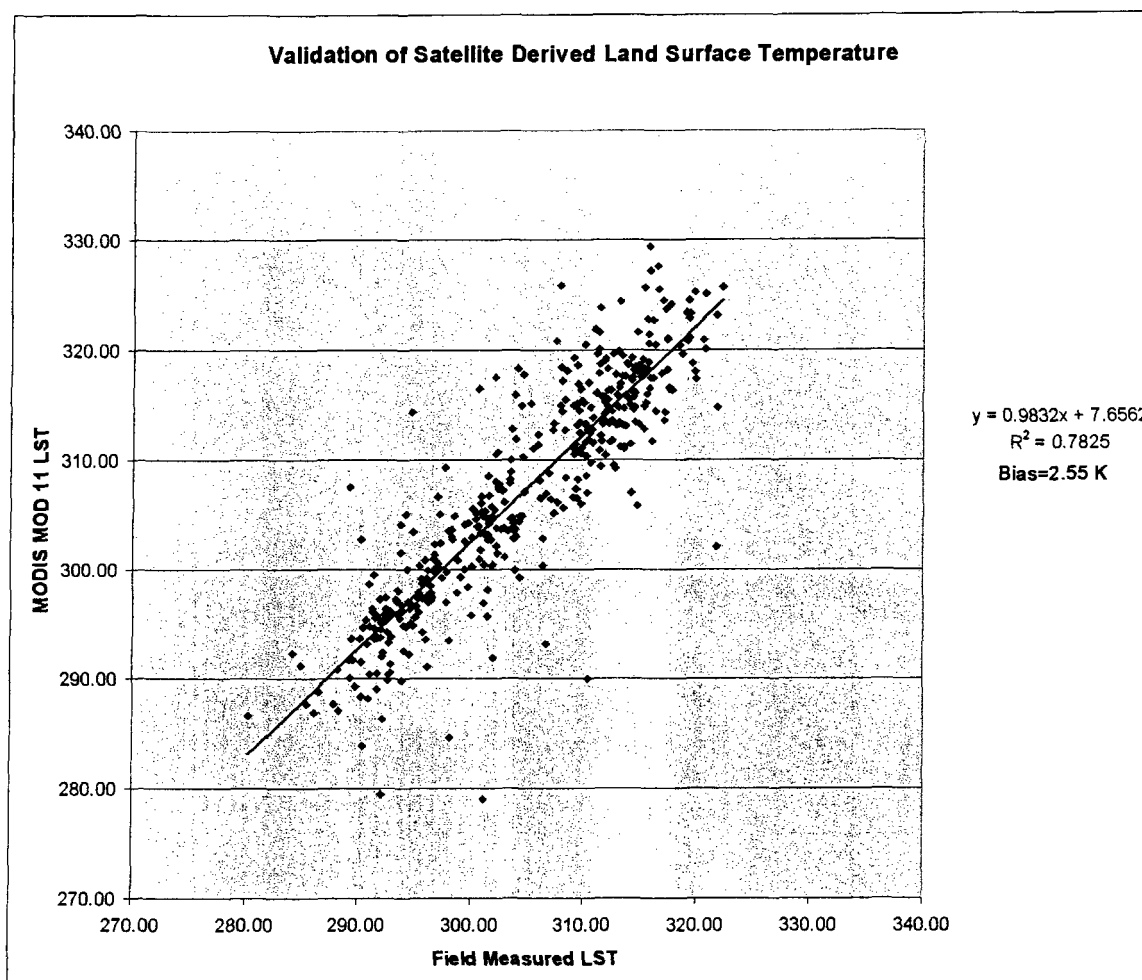


FIGURE 4

Collaboration With Colleagues:

This project was collaborative with PIs at Toledo and Maryland. After rearrangement of responsibilities between Toledo and Maryland during Year 2, the project was been recast but the basic deliverables of the OSU portion were not changed. Personnel from the University of Toledo were in Oklahoma during the summer of 1999 and again in summer 2000. The latter trip was to assist us in installing some field instrumentation at the Marena Mesonet site. In July of 2000, Stadler traveled to Toledo to work on various aspects of the project, especially satellite analysis. The Oklahoma State University portion of the work has become closely tied with Toledo's satellite analysis efforts.

Follow-on Work

The NASA EOS work reported on above started a close cooperation between investigators Stadler and Czajkowski. Outside the period of performance we have begun to study the relationship between MODIS-derived land surface temperature products and Mesonet infrared thermometers. As recently reported at a professional conference (2003), it has become clear that

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the surrounding suite of land uses plays a role in the tightness of fit of a regression line through bivariate plots of infrared thermometers surrounded by rangeland versus infrared thermometers surrounded by cropland. That is, surrounding land use is apparently significant when comparing infrared thermometer output with MODIS land surface temperature products. We intend to develop this theme in the next year.

Publications as a Result of NASA Funding

Langley, Margaret. "The Affect of Mesoscale Landcover on Mesonet Evapotranspiration Estimates" M.S. Thesis, Oklahoma State University **[In progress for Summner 2003]**

Czajkowski, K.P., S.N. Goward, T. Mulhern, S.J. Goetz, A. Walz, S. Stadler, S.D. Prince, and R.O. Dubayah, In Press. "Recovery of Environmental Variables from thermal Remote Sensing." In *Thermal Remote Sensing in Land Surface Processes*, Eds. D. Quattrochi and J. Luvall (Ann Arbor Press: Chelsea, MI) **[IN PRESS FOR 2003]**.

Czajkowski, K..P., S.N. Goward, S.J. Stadler, and A. Walz. 2000. "Thermal Remote Sensing of Near Surface Environmental Variables: An Application Over the Oklahoma Mesonet". In: *The Professional Geographer* . Vol. 52, No. 2, May 2000, pp. 345-357.

Presentations as a Result of NASA Funding

Mather, S., K.Czajkowski, S., and S. Goward "Estimation of Surface and Air Temperature with MODIS Data, Evaluation Using the Oklahoma Mesonet". 98th Annual Meeting of the Association of American Geographers, Los Angeles, April 2002.

Mather, S., K.Czajkowski, S.Stadler, and S. Goward. "Near Surface Variable Estimation with MODIS Data, Validation Using the Oklahoma Mesonet", American Geophysical Union, San Francisco, December 2001.

S.J. Stadler, M. Langley, and L. Schmitz, "Mesoscale Landscape Impacts on Oklahoma Evapotranspiration Estimates." Association of American Geographers, New York City, February 2001.

J. Rose, K. Czajkowski, J. Coss, and S. Stadler "Surface Temperature Validation Using Southern Great Plains Experiment (SGP99) Data." Association of American Geographers, New York City, February 2001.

L. L. Schmitz, M. Langley, and S.J. Stadler, " Analysis of Variables Affecting Warm Season Soil Moisture at 7 Sites Across Oklahoma." Association of American Geographers, New York City, February 2001.

S.J. Stadler and H. Ouaidrari, "A 5-Year Climatology of Mesonetnetwork Data for Validation of Satellite Observations." Association of American Geographers, Pittsburgh, April 2000.

Ouaidrari, H., S. Goward, M. Jun, Y Xue, E. Peters, K. Czajkowski, and S. Stadler, "NOAA-AVHRR Surface Temperature Algorithm for Highly Humid Atmospheres". American Geophysical Union, Seattle, December 1999.